REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
10/05/2015

2. REPORT TYPE

3. DATES COVERED *(From - To)*
Oct 2008-Sep 2015

4. TITLE AND SUBTITLE
A Fixed-Wing Aircraft Simulation Tool for Improving the Efficiency of DoD Acquisition

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Scott A. Morton and David R. McDaniel

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
HPCMP CREATE
10501 Furnace Road Ste 101
Lorton, VA 22079-2624

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
HPCMP CREATE
10501 Furnace Road Ste 101
Lorton, VA 22079-2624

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A

13. SUPPLEMENTARY NOTES
To be published in Computing in Science and Engineering Vol 18, No. 1 Jan/Feb 2016

14. ABSTRACT
The HPCMP CREATETM-AV Kestrel software product is a modularized, multi-disciplinary fixed-wing virtual aircraft simulation tool incorporating aerodynamics, structural dynamics, kinematics, and kinetics. Kestrel allows crossover between simulation of aerodynamics, dynamic stability and control, structures, propulsion, and store separation. The current version of Kestrel is being used extensively in the government aircraft acquisition process, and is being evaluated by industry for suitability to aircraft acquisition. Current capability is demonstrated for a maneuvering aircraft coupled with control surface movements, aeroelastic effects, stores separation, and cargo deployment. Future capabilities are also discussed.

15. SUBJECT TERMS
HPCMP CREATE, Digital engineering, acquisition engineering, aircraft design, airframe testing.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Kevin Newmeyer
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UU	9	**19b. TELEPHONE NUMBER** *(include area code)*
UU	UU	UU			703-812-4417

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

A Fixed-Wing Aircraft Simulation Tool for Improving the Efficiency of DoD Acquisition

Scott A. Morton* and David R. McDaniel†

DOD HPCMP-CREATE™ Kestrel Team, Eglin AFB, FL 32542

The HPCMP CREATE™-AV *Kestrel* software product is a modularized, multi-disciplinary fixed-wing virtual aircraft simulation tool incorporating aerodynamics, structural dynamics, kinematics, and kinetics. *Kestrel* allows cross-over between simulation of aerodynamics, dynamic stability and control, structures, propulsion, and store separation. *Kestrel* is written in modular form with a Python infrastructure to allow growth to additional capabilities as needed. The current version of *Kestrel* is being used extensively in the government aircraft acquisition process, and is being evaluated by industry for suitability to aircraft acquisition. Current capability is demonstrated for a maneuvering aircraft coupled with control surface movements, aeroelastic effects, store separation, and cargo deployment. In addition, several future capabilities currently in prototype are discussed.

I. Introduction

THE Department of Defense High Performance Computing Modernization Program (DOD HPCMP) has been involved in an initiative to improve DOD acquisition program timeline, cost, and performance through the use of Computational Science and Engineering (CSE) tools for ships, aircraft, and antenna design and analysis. The proposed method of improving acquisition is by a paradigm shift from "design-build-fly-fix" to "design-simulate-fix-build-fly." It is well known that the majority of life cycle costs are established early in the design process when the least amount of information is known about deficiencies in the design. This is true because deficiencies are discovered primarily in flight test when they are the costliest to fix. The new methodology uses high resolution, multi-disciplinary, simulations to allow discovery of these deficiencies early in the design phase before the majority of costs are fixed. Fulfillment of this paradigm shift requires system-level high-resolution simulation capabilities that did not exist at the time the DoD initiative started and is the focus of the resulting program.

The resulting effort is called the Computational Research and Engineering Acquisition Tools and Environments (CREATE) Program [1] established in October of 2007. HPCMP CREATE is a tri-Service (Army/Navy/Air Force) program with 10 software products. The air vehicle portion of CREATE is referred to as CREATE™-AV [2] and has three software products CREATE™-AV *Kestrel* [3-11], a high fidelity fixed wing vehicle simulation tool, CREATE™-AV *Helios* [12-14], a high fidelity rotary wing vehicle simulation tool, and CREATE™-AV *DaVinci* [15-16], a conceptual through detail aircraft design tool. In addition to these three products, an emphasis on propulsion systems and their integration into air vehicles is incorporated into each of the three products, referred to as CREATE™-AV *Firebolt* [17-20].

There are several over-arching design philosophies being applied to CREATE software products [1]. The first is scalability on next-generation computer architectures with linear scalability targets for *Kestrel* on the order of 10^4 cores. Another CREATE design philosophy is a "legacy to native" software

* Senior Research Engineer, 201 West Eglin Blvd, Suite 115, AIAA Associate Fellow.

† Research Engineer, University of Alabama Birmingham, AIAA Senior Member.

development approach with near-term legacy software being rewritten or factored in to native software over the life of the program. The current version of *Kestrel* (version 5) represents a mix of native components with some legacy libraries (e.g. parMETIS [21], SAMRAI [22], libmo [3]). One exception to this is the finite-element structural component used in collaboration with the Department of Energy's (DOE) Sandia National Laboratories, called *Sierra/SD* (formerly referred to as *Salinas*) [23,24]. *Sierra/SD* will continue on its development path with the DOE and be incorporated as a whole.

Another important CREATE software design philosophy is modularity. A common architecture in CREATE™-AV is a Python-based infrastructure and executive, and either Python, C, C++, or Fortran components. This level of modularity allows a build-up approach to adding capability and multi-disciplinary physics. The resulting factored approach to the software aids in code maintenance and supportability. A more detailed look at the *Kestrel* architecture is presented below.

One of the most important CREATE design philosophies is to follow a professional software development process incorporating configuration management, automatic unit, integration, and system testing, and user support. To have the desired impact on the DOD acquisition processes, the software has to be maintainable through the life of the program. All CREATE™-AV products have strict version control and configuration management through a Subversion (SVN) repository and *Kestrel* has continuous integration through nightly unit, integration, and system testing. *Kestrel* v5 currently has over 14,000 unit, integration, and system tests all integrated into an overnight regression test harness. User support has both issue tracking and multi-layer live customer support.

The *Kestrel* software product is a modularized, multi-disciplinary fixed-wing virtual aircraft simulation tool incorporating aerodynamics, structural dynamics, kinematics, and kinetics. *Kestrel* is targeted to subsonic, transonic, and supersonic flight conditions. The following sections present the *Kestrel* software architecture, as well as, *Kestrel* current capabilities, and future capabilities.

II. *Kestrel* Software Architecture

The *Kestrel* architecture is a blend of the CREATE design philosophies discussed in the previous section. There are many levels of modularity possible within the architecture but *Kestrel* implements a fairly low-level component design. This choice of modularity allows a component such as the computational fluid dynamics (CFD) solver to be rewritten quickly as methodologies mature, because the component's only purpose is to bring the solution from one time level to the next. Auxiliary functions, such as mesh management or output, are handled in other components. It is a modular approach, factoring traditional monolithic solvers into the CREATE™-AV Common Scalable Infrastructure (CSI) piece; components to perform fluid dynamics, structures, kinematics and kinetics and other analysis; and the *Kestrel* User Interface (KUI). Figure 1 depicts a notional view of the *Kestrel* software architecture. The CSI is an event-driven Python infrastructure that is component-unaware. The components themselves can produce or respond to events and subscribe to or publish data.

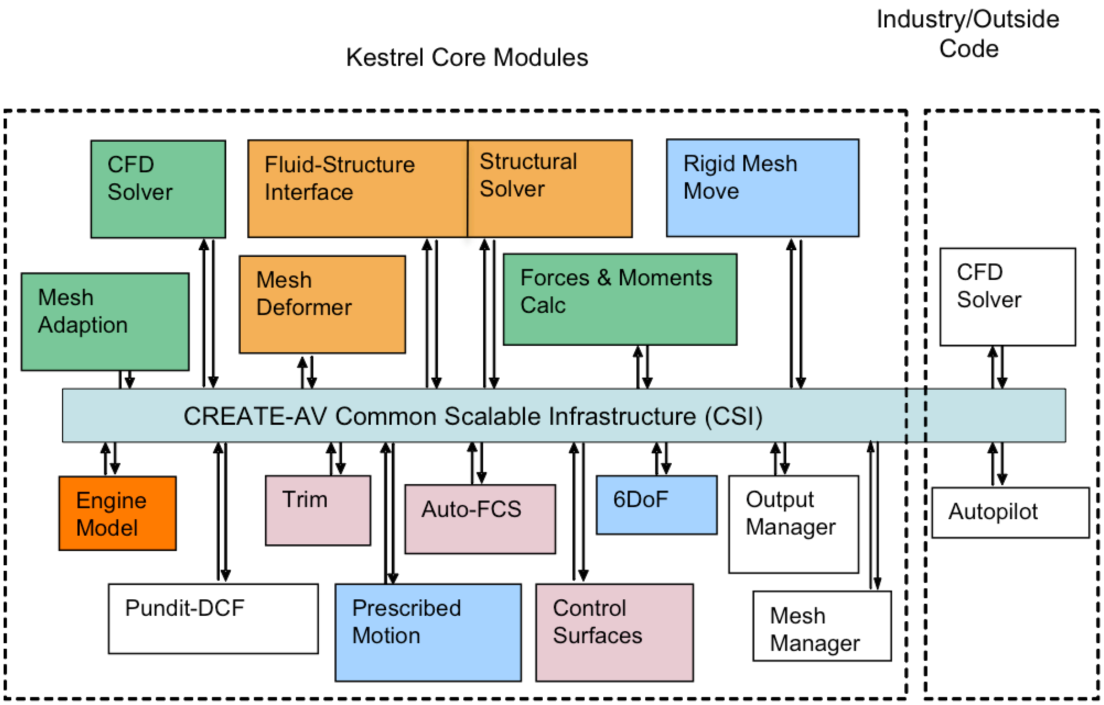

Figure 1: *Kestrel* Architectural Design.

This allows the infrastructure and executive to be coded once and the EXtensible Markup Language (XML) input file to specify the use-case and contributing components. The inputs to CSI are read in from an XML file generated by the KUI. Efficient data handling by CSI is accomplished by passing pointers to “heavy-weight” data or scalars. The resulting overhead was measured at less than 1% compared to a monolithic solver. A detailed look at the *Kestrel* CSI, KUI, and the components is found in reference [4].

In Figure 1 there are two dashed boxes surrounding the components. The left-hand box denotes those components that are shared objects within the CSI and maintained by the *Kestrel* development team. The right-hand box represents executables or shared objects from outside sources that will exchange information via the Data Warehouse in the CSI and the established set of shared data items. This feature, used by a few collaborators and referred to as the *Kestrel* Software Developer Kit (SDK), is discussed in reference [4], and is intended to allow industry or commodity software to work with *Kestrel* without significant rewrites of their software. An example use of this feature is to allow a commodity CFD solver to be used with all of the other components in *Kestrel*. Another example use would be to incorporate a “black-box” automatic flight control system from another contractor into the simulation.

There are two new capabilities in *Kestrel* v5 that also bring new components with them. The first is an improved fluid-structure interaction (FSI) capability that adds a new finite-element structural solver component to the currently available modal structural solver component. *Kestrel* v5 expands the ability to perform aeroelastic simulations by coupling the flow solver, KCFD, with a structural dynamics finite-element analysis package, *Sierra/SD* [23,24], developed by DOE’s Sandia National Laboratories. The forces and displacements are interpolated between the two models (KCFD and Sierra/SD) using the same spline interpolation schemes as are used with the modal structural solver, but the information exchange only occurs once each iteration, reducing the accuracy of the coupled simulation to 1st-order. Future improvements to the *Sierra/SD* component will allow coupling that results in a scheme with globally 2nd-order temporal accuracy. The *Sierra/SD* integration is discussed in more detail in reference [7].

The other new capability is improved aerodynamics through a hybrid unstructured near-body solver coupled to a higher-order Cartesian off-body solver that incorporates in-line adaptive mesh refinement and load balancing. This hybrid approach has been used extensively in *Helios* to simulate rotor wake-fuselage interactions [13,14]. The near-body solver is the current KCFD component unchanged. The off-

body Cartesian solver is an enhancement to the SAMCart component used in the *Helios* rotorcraft product. The original Helios implementation focused on the rotorcraft flowfield requirements and was called SAMARC [13,14]. Eymann et. al. [6] enhanced the original component to include implicit time-stepping, shock capturing for transonic and supersonic fixed-wing applications, and improved turbulence modeling. The enhanced SAMCart component is currently being used in *Kestrel* and will be used in *Helios* future versions. A detailed look at how SAMCart uses the SAMRAI [22] automatic mesh generation and load balancing routines, as well as a discussion of the modified Cartesian flow solver can be found in reference [6]. The near-body and off-body solvers couple at the subiterative level using PUNDIT [12], an implicit hole-cutting domain connectivity component to calculate donor and receptor cells, as well as interpolation weights for data transfer between the respective meshes, previously used in *Kestrel* for unstructured-to-unstructured mesh overset connectivity.

III. *Kestrel* Current Capability

The development schedule of *Kestrel* is broken up into two-week iterations following an agile software development process. These two-week iterations result in incremental tested and documented capability that is available to the user long before the targeted version is complete. Iteration flexibility also allows the Quality Assurance and Development Teams to work together to satisfy user issues and high-priority interrupt requirements. Below is a bulleted list of *Kestrel* v5 capabilities.

***Kestrel* v5 Capability:**

1. **Static Rigid Aircraft**
    - **Single- and Multi-Body**
2. **Prescribed and Predicted 6DoF Motion of Rigid Aircraft**
    - **Single- and Multi-Body**
    - **Prescribed Control Surfaces**
3. **Static, Prescribed, and Predicted Aeroelastic Single-Body Aircraft**
    - **Modal Structural Coupling**
    - **Finite-Element Structural Coupling**
4. **Aircraft-Engine Integration Model Inclusion in 1-3 Above**
    - **Propulsion Cycle Analysis**
      Fully-Coupled
5. **All Unstructured Mesh or Hybrid Near-Body/Off-Body Solution Paradigm**
    - **Homogeneous Unstructured Mesh Overset**
    - **Hybrid Unstructured/Cartesian Mesh Overset**

Kestrel major versions are released annually. *Kestrel* v5.3 is currently in general release to users. *Kestrel* v6 is currently in Quality Assurance (QA) testing, and *Kestrel* v7 is in design and implementation.

IV. *Kestrel* Version 5 Sample Case

This section presents a sample case of a multi-disciplinary solution computed with *Kestrel v5.* This sample case is one of four different multi-disciplinary cases described in detail in [5]. These cases all have combinations of traditional capabilities in use at the same time (e.g., maneuvers with either control surfaces moving, or aeroelastic bodies, or store separation, as well as six degree-of-freedom cargo deployments).

Sample Complex Case – Maneuvering F-16 Releasing Multiple Stores

The sample case involves an F-16 multiple store release while in a Wind Up Turn (WUT) maneuver. The WUT motion is initiated by accelerating the aircraft from a Mach number of zero to a Mach number of 0.6. After stabilizing at this Mach number for 1 sec, over the next few seconds the aircraft rolls to a bank angle of greater than 90 degrees. For the remaining 6 seconds, the bank angle is relaxed to less than 80 degrees, and the pitch angle is changed to establish the maximum angle-of-attack. The left store is

released at t=5.5 seconds and the right store is released at t=6.0 seconds. The store used is a 500 lb class GBU-38 guided munition.

The aerodynamic volume mesh for the F-16 used in the simulation has 6.5M tetrahedra, 3.8M prisms, and 19.5K pyramids. The aerodynamic volume mesh used for the GBU-38 in the simulation has 1.6M tetrahedra, 2.4M prisms, and 14.4K pyramids. The same GBU-38 mesh is used for both the left and right stores. The combined system of three meshes is depicted in Figure 2. The three unstructured mesh system was solved with the unstructured to unstructured overset capability in *Kestrel*.

Figure 2: Surface mesh of an F-16 with two under-wing GBU-38 stores placed approximately at the mid-wing pylon stations.

The simulation was performed using a time-step of 0.0005 seconds, 3 subiterations, and inner sweeps that converge the linear problem to a residual of 1.0×10^{-6}. Figure 3 is a series of snapshots of the maneuver and store releases at various points in time, depicting surface pressures and iso-surfaces of vorticity magnitude of 100/sec. Figure 3a depicts the F-16 with the left and right store in carriage position at t=2 seconds when the aircraft is beginning the roll to the right. Figure 3b depicts the F-16 with both stores in carriage at t=4 seconds, after the bank has been established but before the aircraft loads up to maximum angle-of-attack. Figure 3c depicts the aircraft at t=6 seconds, 0.5 seconds after the left store was released and at the instant when the right store was released. Figure 3d depicts the aircraft at t=6.5 seconds where it is clear that both stores have been released, and they are traveling along a nearly horizontal trajectory away from the aircraft as it continues the WUT. Finally, Figure 3e depicts the aircraft and stores at the end of the 10 second simulation. It is clear that the stores have traveled significantly away from the aircraft, but are still flying primarily at the same altitude as the F-16. At this point the store meshes are interpolating data from a very coarse part of the aircraft mesh, and the fluid solution is somewhat non-physical though stable. However, the inertial motion of the stores dominates the trajectory at this point, and the flow solution accuracy is not critical.

Use of Kestrel's Near Body-Off Body mesh paradigm would alleviate these inaccuracies and will be used for future store release cases. Analyzing the positions of the three bodies as a function of time shows the stores traveling down range for over 1.26 miles with a vertical drop of 833 feet of altitude during the full 10 seconds. A simulation of this complexity and accuracy can aid in developing new methods of weapons delivery. For example, it is not typical for DOD aircraft to release stores during a loaded turn, but if this became desirable for some operational need in the future, *Kestrel* could simulate it.

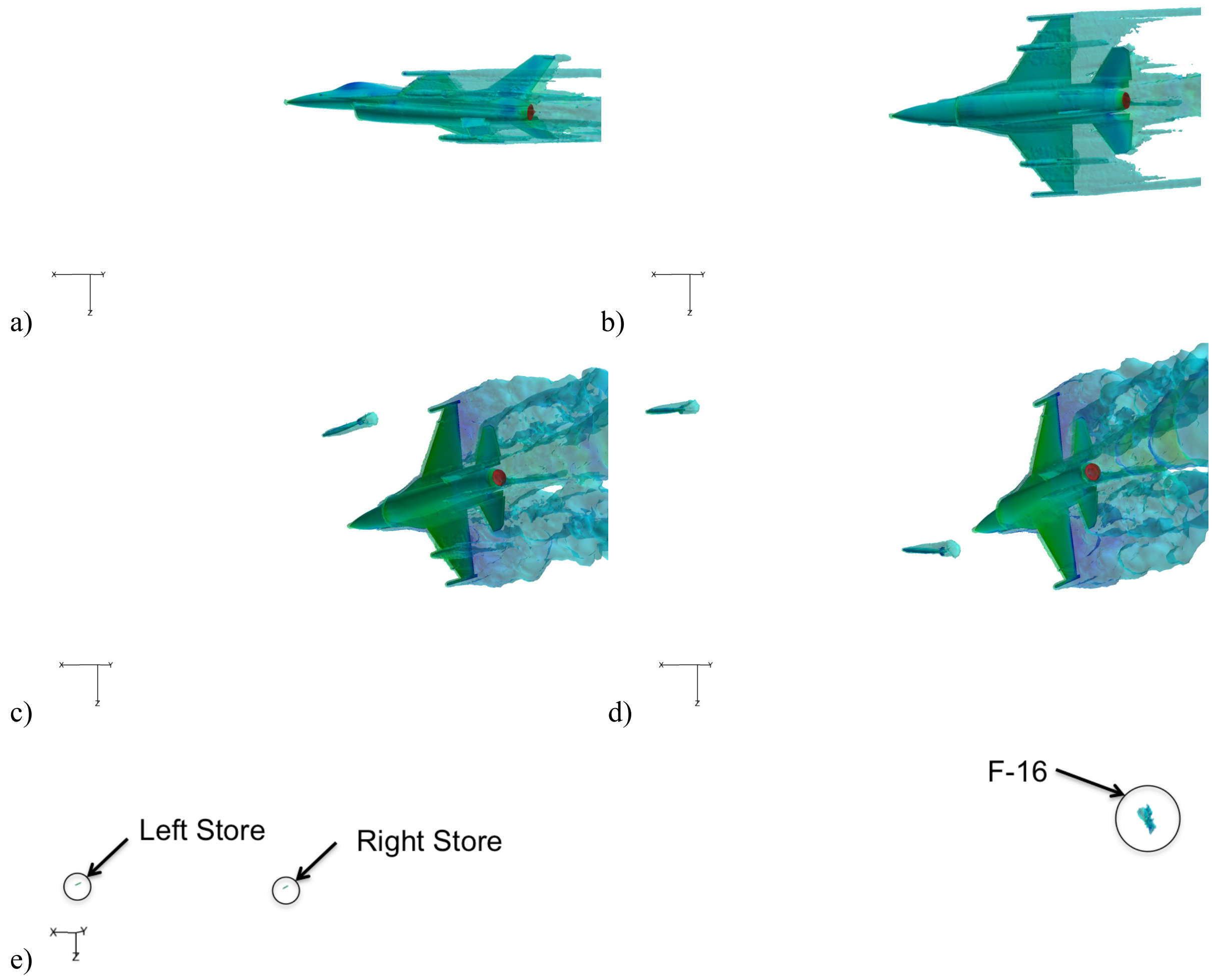

Figure 3: Snapshots of surface pressures and iso-surfaces of vorticity magnitude equal to 100/sec for an F-16 with left and right under-wing stores releasing at 5.5 and 6.0 sec, respectively, for a Mach number of 0.6. The maneuver is a 10 sec maximum angle-of-attack wind-up turn. Images are at various time steps, a) t=2.0 sec, b) t=4.0 sec, c) t=6.0 sec, d) t=6.5 sec, e) t=10 sec.

V. *Kestrel* Future Direction

There are several areas of active *Kestrel* development in the *Kestrel* Fixed-Wing and Propulsion Groups, as well as the CREATE^{TM}-AV Quality Assurance Team. *Kestrel* v6 includes cross-cutting improvements in speed, scalability, and accuracy, and a significant reduction in required memory per core for simulations with a large number of surface elements.

One of the much-anticipated *Kestrel* v6 capabilities is the Propulsion Capability 2 that introduces rotating turbo-machinery for simulation of complex compressors integrated into the inlet. Nichols et al. [18] present results for turbo-machinery component cases of increasing complexity, including the Rotor35, Stage35, Rotor67, and Rotor67 in a serpentine inlet duct comparison cases. Klepper et al. [19] also present simulations of the full A-10 aircraft with one of the engines simulated with engine cycle analysis and the other engine simulated with an installed compressor fan rotating at 6500 RPM.

Another new capability coming in *Kestrel* v6 related to propulsion integration is the capability to simulate the exit nozzle variable throat and exit plane. Masters [20] presents results for a variable geometry nozzle for the F-110 engine installed in the F-16XL. The variable nozzle geometry can

currently be prescribed as a function of time, but will eventually be tied to the propulsion cycle analysis model of the engine to automatically drive the geometry variation with throttle position and flight condition.

The final new capability to be discussed is the ability to couple an automatic flight control to *Kestrel* to drive the motion of bodies, or control surfaces, or modify flowfield source terms in response to the flowfield. Forsythe et.al. [10] present simulations of a helicopter, with a modeled actuator disk driven by the CASTLE [10] aircraft simulation tool, landing on a carrier deck. This work demonstrates the ability to couple a "black-box" external executable to *Kestrel* using memory on the cores, as opposed to a file IO approach (FIFO) by using the *Kestrel* Software Developer Kit [4].

VI. Conclusions

In conclusion, significant progress has been made since the inception of the CREATE Program in October of 2008. In the CREATE™-AV *Kestrel* Team, requirements have been gathered, refined, and prioritized; software capabilities to meet the requirements have been defined; the software has been designed, implemented, tested, and distributed to users for version 1 through 5; version 6 is in alpha testing; and version 7 is in design. The *Kestrel* software product has been developed following the over-arching design philosophies of the CREATE Program and to meet the specific needs of the aircraft acquisition engineer and scientist communities. In addition, *Kestrel* has been developed from the ground up following sound software development practices, and innovative solutions to the user requirements have resulted from the process. An intensive validation and verification effort is perpetually underway to ensure *Kestrel* is suitable for production use by the acquisition community. A sample result for the v5 release capabilities has been presented and a look into capabilities currently in prototype that will be available in the near future have also been presented.

Acknowledgments

Material presented in this paper is a product of the CREATE™-AV Element of the Computational Research and Engineering for Acquisition Tools and Environments (CREATE) Program, sponsored by the U.S. Department of Defense HPC Modernization Program Office, part of the US Army Corps of Engineers Engineer Research and Development Center. The authors would also like to acknowledge the contributed efforts of Dr. Tim Eymann, Dr. Steven Lamberson, Mr. Patrick McNally, Mr. Robert Starr, and Mr. Todd Tuckey of the Kestrel Fixed-Wing Group; Mr. Wes Cothran, Dr. Greg Denny, Ms. Bonnie Heikkinen, Mr. Travis Horine, Mr. Jason Klepper, Dr. Jim Masters, and Dr. Robert Nichols of the Kestrel Propulsion Group; Dr. Jen Abras, Dr. Jim Forsythe, Mr. Ben Hallissy, Mr. Dave Hine, Dr. Joe Laiosa, Mr. Chad Lillian, and Dr. Theresa Shafer of the Quality Assurance Team, and Mr. Stephen Adamec, Mr. Brian Pittman, Dr. Jay Sitaraman, and Dr. Andrew Wissink of the CREATE™-AV Integration Team. Finally, the CREATE Management Team for their management support and the 96 Test Wing RNCS/RNCE for their facility and financial management support.

References

[1] Post, D., Arevalo, S., Atwood, C., Bell, P., Blacker, T., Dey, S., Fisher, D., Fisher, D.A., Genalis, P., Gorski, J., Harris, A., Hill, K., Hurwitz, M., Kendall, R., Meakin, R., Morton, S., Moyer, E., Strawn, R., van Veldhuizen, D., Votta, L., Wynn, S. and Zelinski, G., *Journal of Physics*: Conference Series vol. 125 (2008) 012090.

[2] Meakin, R., Atwood, C., and Hariharan, N., "Development, Deployment, and Support of a Set of Multi-Disciplinary, Physics-Based Simulation Software Products," 49th AIAA Aerospace Sciences Meeting, Orlando, Florida, 4-7 January 2011.

[3] Morton, S., Eymann, T., McDaniel, D., Sears, D., Tillman, B., Tuckey, T., "Rigid and Maneuvering Results with Control Surface and 6DoF Motion for Kestrel v2," AIAA Paper 2011-1106, 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, 4-7 January 2011.

[4] McDaniel, D., Tuckey, T., “Multiple Bodies, Motion, and Mash-Ups: Handling Complex Use-Cases with Kestrel,” AIAA Paper 2014-0415, 52nd Aerospace Sciences Meeting, National Harbor, Maryland, 13-17 January 2014.

[5] Morton, S., McDaniel, D., “HPCMP CREATE™-AV Kestrel Current Capabilities and Future Direction for Fixed-Wing Aircraft Simulations,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[6] Eymann, T., Nichols, R., Tuckey, T., McDaniel, D., “Cartesian Adaptive Mesh Refinement with Kestrel,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[7] Lamberson, S., Hallissy, B., “Aeroelastic Simulations with Modal and Finite-Element Structural Solvers Using CREATE™-AV/Kestrel v5,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[8] Smith, B., “An Assessment of CREATE-AV Kestrel for F-35 Aero/Performance Applications,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[9] Stookesberry, D., “An Industry Assessment of CREATE-AV Kestrel,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[10] Forsythe, J., Lynch, E., Polsky, S., “Coupled Flight Simulator and CFD Calculations of Ship Airwake Using Kestrel,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[11] Shafer, T., Eymann, T., Forsythe, J., Hallissy, B., Hine, D., “Applications of CREATE™-AV Kestrel v5 with Cartesian Adaptive Mesh Refinement,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[12] Sitaraman, J., Floros, M., Wissink, A., and Potsdam, M., “Parallel Domain Connectivity Algorithm for Unsteady Flow Computations Using Overlapping and Adaptive Grids,” Journal of Computational Physics, Vol. 229, 2010, pp. 4703–4723.

[13] Wissink, A. M., Kamkar, S., Pulliam, T. H., Sitaraman, J., and Sankaran, V., “Cartesian Adaptive Mesh Refinement for Rotorcraft Wake Resolution,” 28th AIAA Applied Aerodynamics Conference, 2010, AIAA Paper 2010-4554.

[14] Kamkar, S. J.,Wissink, A. M., Jameson, A., and Sankaran, V., “Automated Off-Body Cartesian Mesh Adaptation for Rotorcraft Simulations,” 49th AIAA Aerospace Sciences Meeting, 2011, AIAA Paper 2011-1269.

[15] Rooney, B., “The CREATE-DaVinci Power User Experience,” AIAA Paper 2014-0921, 52nd Aerospace Sciences Meeting, National Harbor, Maryland, 13-17 January 2014.

[16] Brooks, G., “CREATE™-AV DaVinci 3.0 and Capstone Integration,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[17] Denny, A., Horine, J., Nichols, R., Morton, S., Klepper, J., Savelle, S., “Inlet/Engine Integration Examples Using Coupled Transient and Steady Engine Performance Models with Kestrel,” AIAA Paper 2014-0753, 52nd Aerospace Sciences Meeting, National Harbor, Maryland, 13-17 January 2014.

[18] Nichols, R., McDaniel, D., Tuckey, T., Koomullil, R., Ito, Y., Klepper, J., “Firebolt c2.0 – Unstructured Grid Navier-Stokes Code for Airframe/Propulsion Integration,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[19] Klepper, J., Nichols, R., Jenkins, J., “A-10 Analysis Using HPCMP CREATE™-AV Kestrel Product Utilizing the Firebolt Propulsion Component,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[20] Masters, J., “Dynamic Modeling of an Aircraft Primary Nozzle During Maneuver,” 53rd AIAA Aerospace Sciences Meeting, Kissimmee, Florida, 5-9 January 2015.

[21] Karypis, G., Schloegel, K., and Kumar, V., “*Parmetis: Parallel Graph Partitioning and Sparse Matrix Ordering Library, Version 3.1*,” Technical report, Dept. Computer Science, University of Minnesota, 2003.

[22] Anderson, R., Arrighi, W., Elliott, N., Gunney, B., and Hornung, R., “SAMRAI Concepts and Software Design,” LLNL-SM-617092-DRAFT, Lawrence Livermore National Laboratory, February 2013.

[23] Bhardwaj, M., Pierson, K., Reese, G., et al, *Salinas*: a scalable software for high-performance structural and solid mechanics simulations, Proceedings of the 2002 ACM/IEEE conference on Supercomputing, 2002.

[24] Rouse, J.W., Walsh, T.F., Reese, G.M., *Salinas*: A massively parallel Finite element code for structural dynamics and acoustic analysis., J. Acoust. Soc. Am., Vol. 129, No. 4, 2011.